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EFFECT OF THE BOUNDARIES OF AN INCOMPRESSIBLE FLUID FLOW ON THE UNSTEADY AERODYNAMIC CHARACTERISTICS OF A PROFILE

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EFFECT OF THE BOUNDARIES OF AN INCOMPRESSIBLE FLUID FLOW ON THE UNSTEADY AERODYNAMIC CHARACTERISTICS OF A PROFILE

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ABSTRACT

Influence of flow boundary effects on airfoils within linear theory is discussed. Solid wall, free liquid or mixed boundaries are compared. Movement in and out of phase is evaluated. The value of the Strouchal number is discussed.

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The evaluation of flow boundary effects on the aerodynamic characteristics of the body in the flow is of great practical interest. Thus, for example, when experiments are carried out in a wind tunnel with a closed or open working section the effect of tunnel walls or of the flow boundaries on the aerodynamic characteristics of the test model should be taken into account. Since the problem is very complex, the usual procedure is to consider only two-dimensional flow. If the flow body is situated symmetrically with respect to the flow boundaries, the problem is reduced to the investigation of the flow near the cascade of bodies with a zero stagger and pitch equal to the distance H between the flow boundaries.

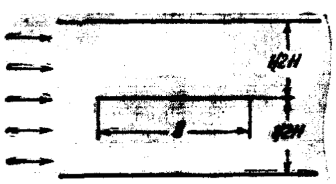

Figure 1.

* Numbers in margin indicate pagination in original foreign text

In the present work, which is formulated on the basis of linear theory, the effect of flow boundaries associated with an incompressible fluid on the nonstationary aerodynamic characterics of a thin slightly curved airfoil undergoes harmonic oscillations with small amplitude (Figure 1). As we know, in this case the theory of cascades makes it possible to investigate three types of rectilinear flow boundaries: both boundaries represented by solid wall; both boundaries represented by free liquid surfaces; one boundary represented by a solid wall and the other by the free liquid surface. The form of the boundary determines the boundary conditions of the problem. Thus in the case of a solid wall, the normal component of the flow velocity is considered to be equal to zero while on the the free surface the tangential component of the perturbed fluid velocity is considered to be equal to zero which in the present case provides for constant pressure along the free surface. For this reason the two dimensional flow around an oscillating airfoil bounded by solid walls corresponds to the flow of fluid near a cascade of airfoils which oscillate out of phase. The free flow boundaries correspond to the cophased motion of the airfoils in the cascade. In regard to the flow bounded by the flat wall and the free surface of the liquid, the airfoils in the /158 cascade move with pairs out of phase while the airfoils in each pair move in phase. It also turns out that all of the airfoils move out of phase with respect to the solid wall and in phase with respect to the free surface.

At the present time there is a series of works which present the results of calculations carried out to determine the nonstationary aerodynamic characteristics of airfoils in a cascade, oscillating in an incompressible flow both in phase and out of phase. See for example refs. 1, 2, 3 . These results make it possible for us to determine the effect of solid and free flow

boundaries on the aerodynamic characteristics of an airfoil.

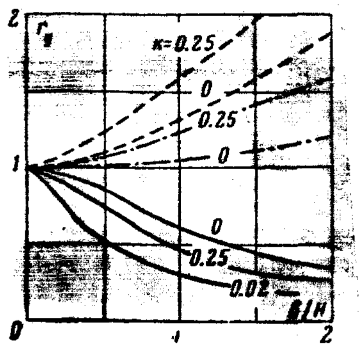

Figure 2.

In the case of mixed boundaries (solid wall and free surface) the calculations can be based on the aerodynamic influence coefficients for the airfoils of the cascade. If we limit our investigation to the case of torsional synchronous oscillations of airfoils, the aerodynamic force L and the aerodymaic moment M acting on the initial airfoil of the cascade may be represented in the following form, as shown in ref. 4,

$$L=\frac{1}{2}\rho V^2 b \sum_{n=-\infty}^{\infty} l_n^{\alpha} \alpha_n e^{i\psi_n}$$
$$M=\frac{1}{2}\rho V^2 b^2 \sum_{n=-\infty}^{\infty} m_n^{\alpha} \alpha_n e^{i\psi_n} \qquad (1)$$

In the above equations ρ is the density of the unperturbed fluid, V is the velocity of the unperturbed flow, b is the chord of the airfoil, α_n is the angular displacement of the n-th airfoil of the cascade with respect to its average position, ψ_n is the phase shift between the oscillations of the n-th and of the initial profile; l_n^{α}, m_n^{α} are the aerodynamic influence coefficients which determine the forces and the moments acting on the initial airfoil when the n-th airfoil oscillates in accordance with an

assigned law.

In the case of mixed flow boundaries the airfoils of the cascade oscillate in such a way that

$$\alpha_n = \alpha, \quad \psi_{2r} = \psi_{2r+1} = r\pi \text{ when } r = 0, \pm 1, \pm 2, \ldots$$

Then, assuming that

$$L = {}^1/_2 \rho V^2 b C_m^\alpha \alpha, \qquad M = {}^1/_2 \rho V^2 b^2 C_y^\alpha \alpha \tag{2}$$

we obtain the following expressions from equations (1) and (2)

$$C_y^\alpha = \sum_{r=-\infty}^{\infty} e^{ir\pi}\left(l_{2r}^\alpha + l_{2r+1}^\alpha\right), \quad C_m^\alpha = \sum_{r=-\infty}^{\infty} e^{ir\pi}\left(m_{2r}^\alpha + m_{2r+1}^\alpha\right) \tag{2a}$$

Since for a cascade without stagger $l_r = l_{-r}$, $m_r = m_{-r}$ we have

$$C_y^\alpha = l_0^\alpha + 2\sum_{r=1}^{\infty}(-1)^r l_{2r}^\alpha, \quad C_m^\alpha = m_0^\alpha + 2\sum_{r=1}^{\infty}(-1)^r m_{2r}^\alpha. \tag{3}$$

We shall represent the dimensionless aerodynamic coefficients C_y^α, C_m^α, in the form

$$C_y^\alpha = |C_y^\alpha| e^{i\varphi_y}, \quad C_m^\alpha = |C_m^\alpha| e^{i\varphi_m}.$$

Here $|C_y^\alpha|, |C_m^\alpha|$ are the moduli , while φ_y, φ_m are the arguments of the corresponding complex coefficients.

We shall designate by $|C_{y\infty}^\alpha|$, $|C_{m\infty}^\alpha|$, φ_{y_∞} , φ_{m_∞} the same quantities for the case of infinite flow. We shall consider the ratios

$$C_y^{\alpha} / C_{y\infty}^{\alpha} = r_y e^{i\Delta\varphi_y}, \quad C_m^{\alpha} / C_{m\infty}^{\alpha} = r_m e^{i\Delta\varphi_m}$$

$$\left(\begin{matrix} r_y = |C_y^{\alpha}| / |C_{y\infty}^{\alpha}|, & r_m = |C_m^{\alpha}| / |C_{m\infty}^{\alpha}| \\ \Delta\varphi_y = \varphi_y - \varphi_{y\infty}, & \Delta\varphi_m = \varphi_m - \varphi_{m\infty} \end{matrix} \right) \qquad (4)$$

The computed values values of r_y, r_m which are of prime interest for solid boundaries (broken line), for free boundaries (solid line) and mixed boundaries (dot dash) are given in Figures 2-4. The computations were carried
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out by using data in references 1-3. The calculated points in Figures 2 and 3 are the values b/H = 0; 0.5, 1, 1.5, 2, while in Figure 4 they are the values k = 0, 0.02, 0.1, 0.25, 0.5, 1.

The results which have been presented show that the effect of flow boundaries becomes a stationary force particularly when b/H > 0.5. In this case the solid boundaries increase while the free boundaries decrease the lift force and moment acting on an airfoil in an infinite flow. For the same values of the paramenter b/H the mixed boundaries have a lesser effect on the flow around the airfoil than the solid and free boundaries.

The effect of flow boundaries depends substantially on the Strouchal number k. The maximum effect, particularly for small values of k, is observed in a flow with free boundaries. A typical nature of this relationship is shown

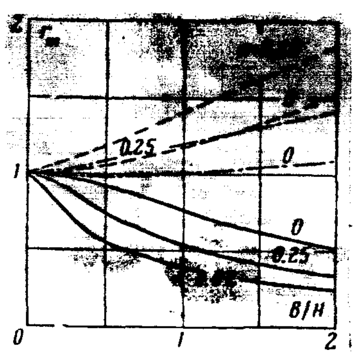

Figure 3.

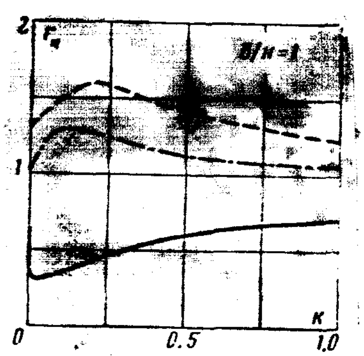

Figure 4.

in Figure 4. We note that in Figures 2-4 the case k = 0 corresponds to the stationary flow. This should be qualified because the nonstationary aerodynamic forces which act on a cascade of airfoils oscillating in phase, for the case k = 0, differ from the corresponding stationary forces by a finite quantity which depends on the geometric parameters of the cascade (ref. 1).

The discontinuity between stationary and nonstationary forces, when k = 0, disappears if the vortex tracks trailing each airfoil of the cascade are assumed to be of finite length or if we consider a cascade containing a finite number of airfoils. The discontinuity is also absent when the oscillations of the cascade airfoils occur with a finite phase shift (ref. 3).

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